On the Use of Printed Hybrid Rocket Motors for Mars Sample-Return and Other Missions

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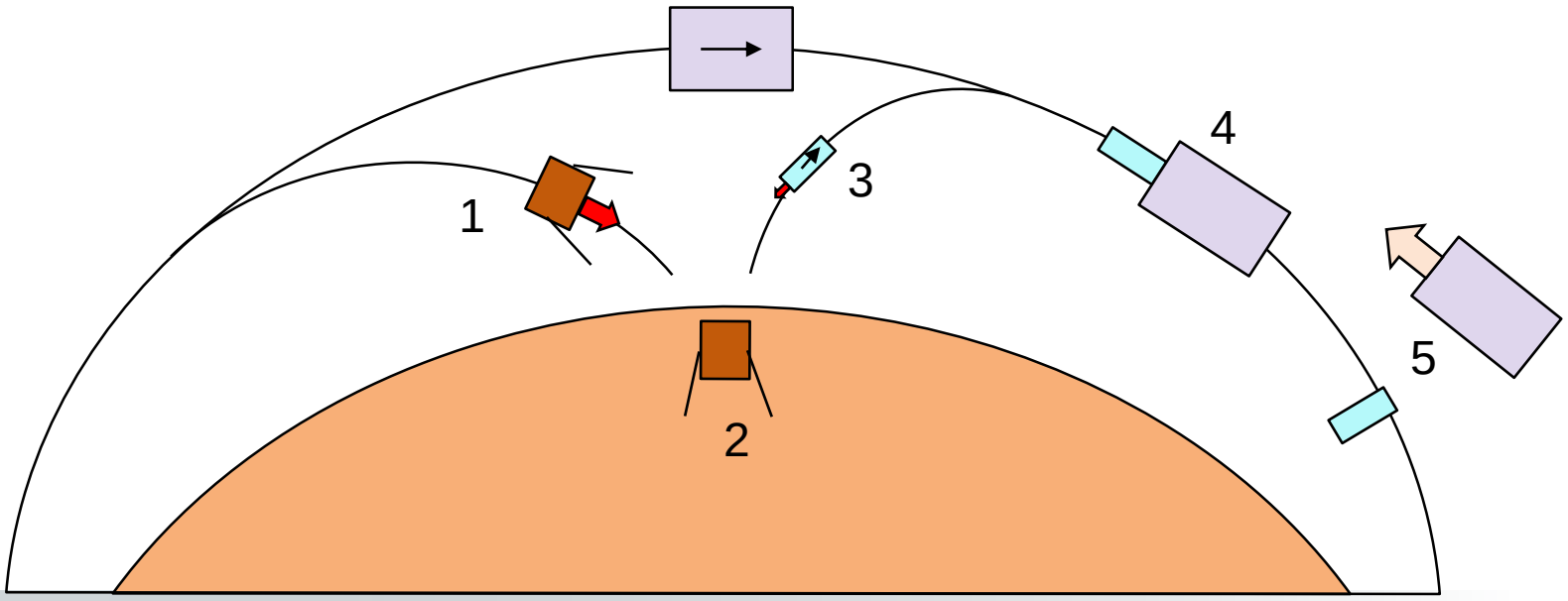
Simple Mission Scenario using Printed Fuel Grains, Printed TVC and Other Aerospace Corporation CubeSat Technology

1. Mother ship heats lander fuel grain, launches lander
2. Lander collects soil sample
3. Lander supplies current to heat Ascent Vehicle fuel grains
4. AV returns to mother ship, transfers sample
5. Mother ship discards Ascent Vehicle, raises orbit, leaves under electric propulsion



Aerospace Critical Technologies for Lander and Sample Return Missions in CubeSat and MicroSat Forms

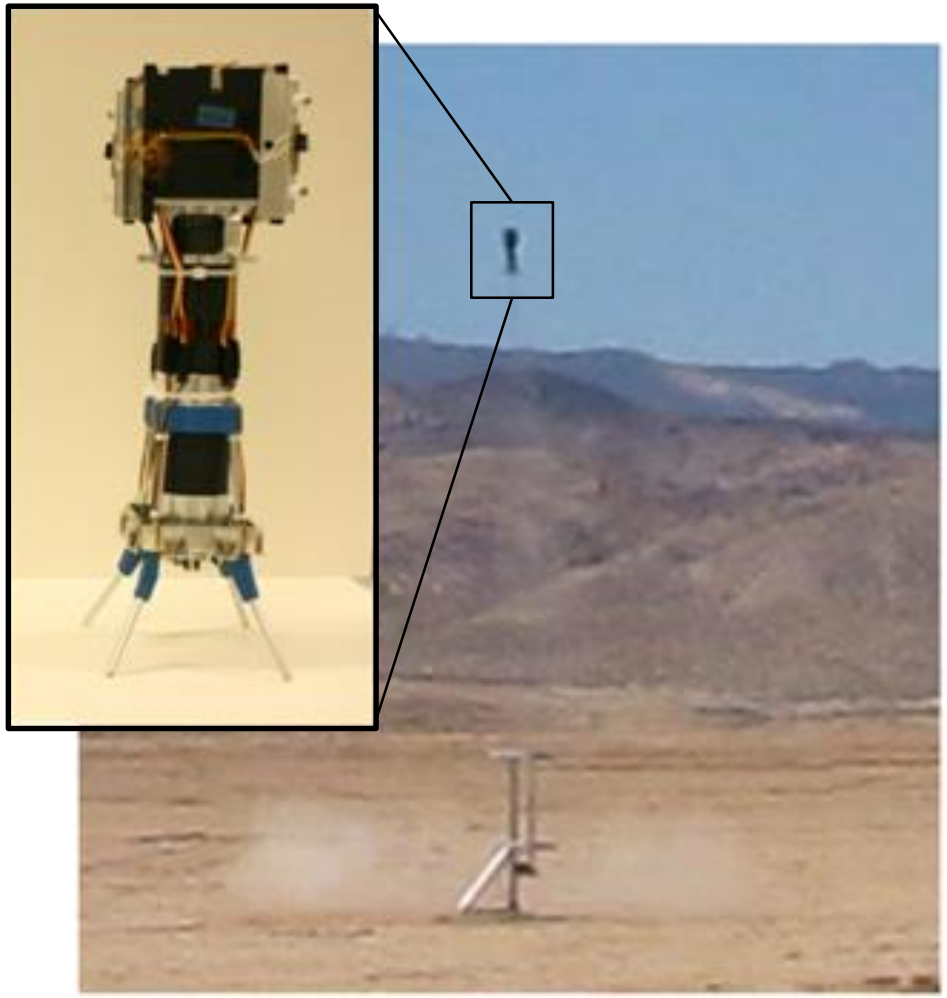
These technologies have flown in CubeSat form or are under development by The Aerospace Corporation's Microsatellite Systems Department

- Printed Hybrid Rocket Motor Fuel Grain
- Thrust Vector Control
- Laser Rangefinding
- Laser Communications
- Miniature Star Tracker
- Ram Direction Sensor
- Optical Detectors
- Electric Propulsion
- ADCS

Printed oxidizer tank (grey) with printed fuel grain (white)

Printed Thrust Vector Control System

- mSAT Low Altitude Tests
- Tried two Thrust Vector Control strategies
- This TVC used printed Inconel “Jet Paddles” to deflect rocket exhaust
- TVC System total mass – 150 grams (not optimized)

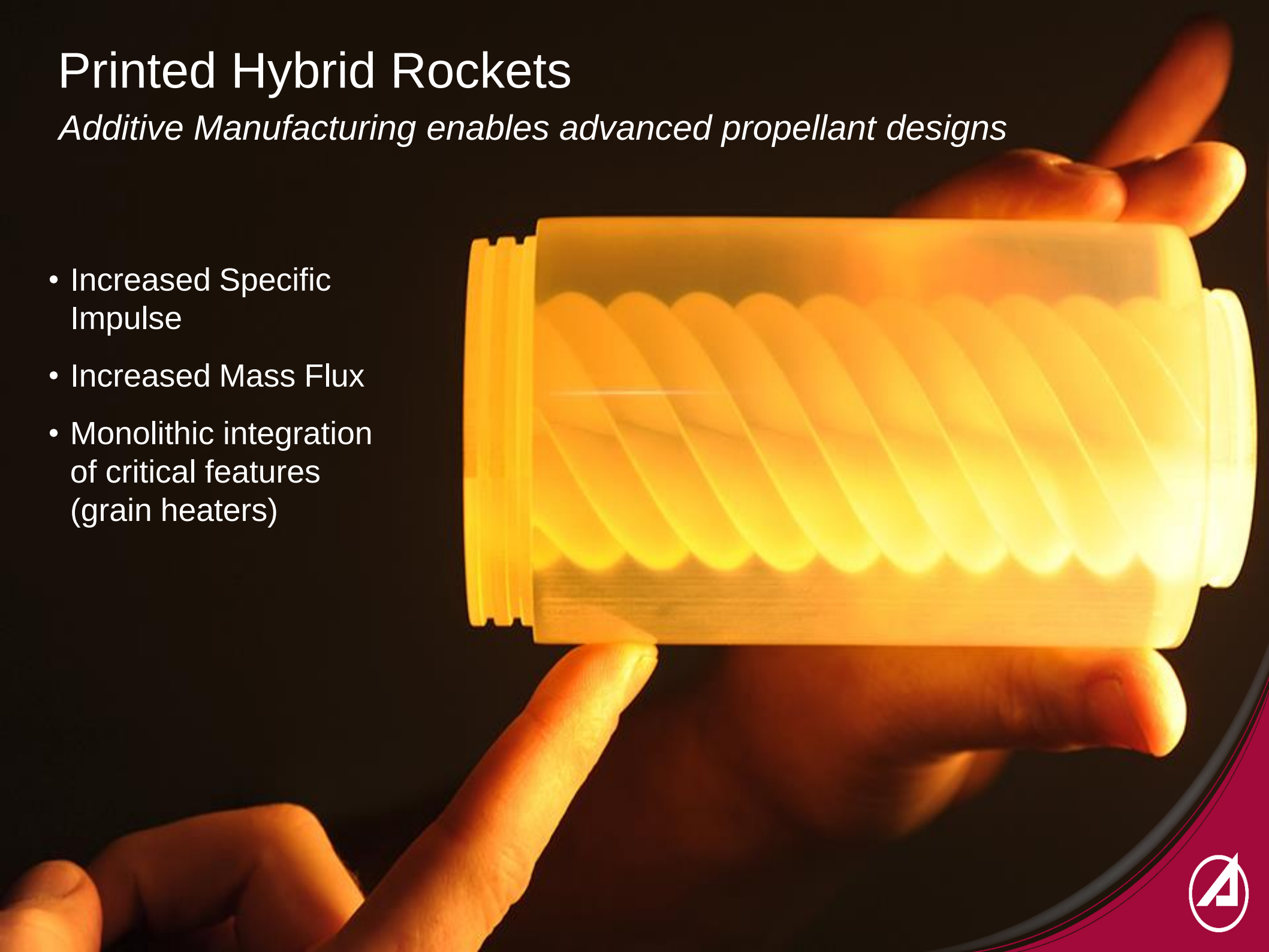


Test flight of TVC system using DMLS parts, Mojave Desert, 2013

Printed Hybrid Rockets

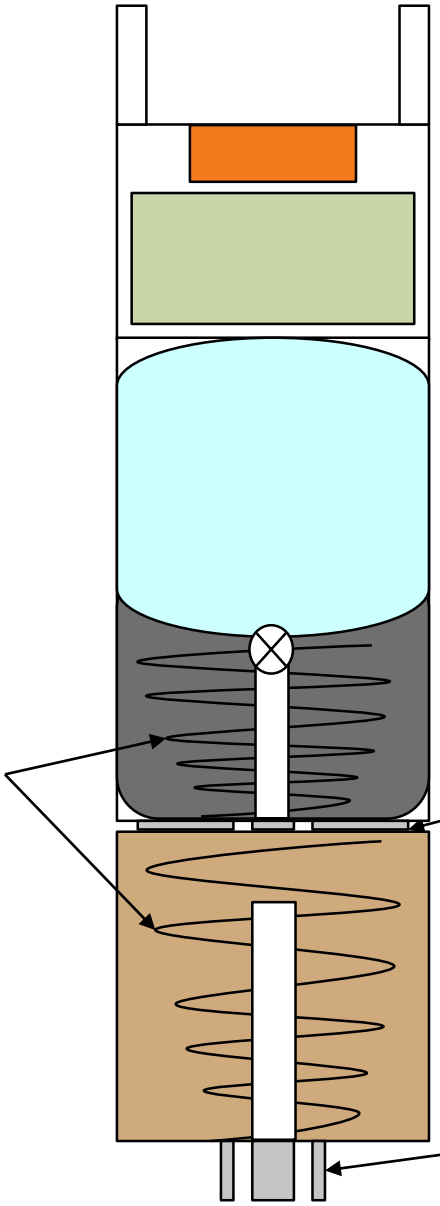
Additive Manufacturing enables advanced propellant designs

- Increased Specific Impulse
- Increased Mass Flux
- Monolithic integration of critical features (grain heaters)



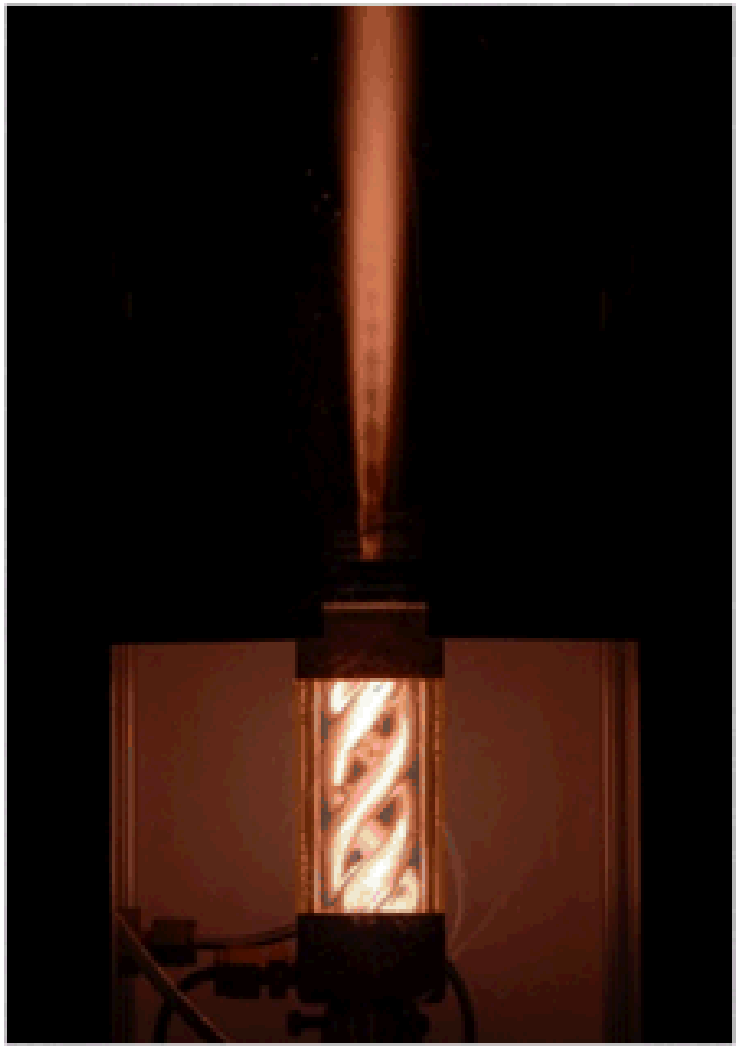
Ascent Vehicle Conceptual Layout

- Two Stage
- Hybrid Upper Stage
- Composite Solid 1st Stage
- Thrust Vector Control
- Integrated grain heaters



Why Print? Additive Manufacturing Enables Conductive Heating – much more effective than Radiation

- AM Allows novel grain shapes and new capabilities
- Introduces non-axially-constant features
  - *Helices, annuli, radial ports*
- Increases burning surface area
- Increases effective length
- New functionality not seen in traditional hybrids
  - *Graded functionality*
  - *Passive control features*
  - *Oxidizer flow manipulation within the grain*



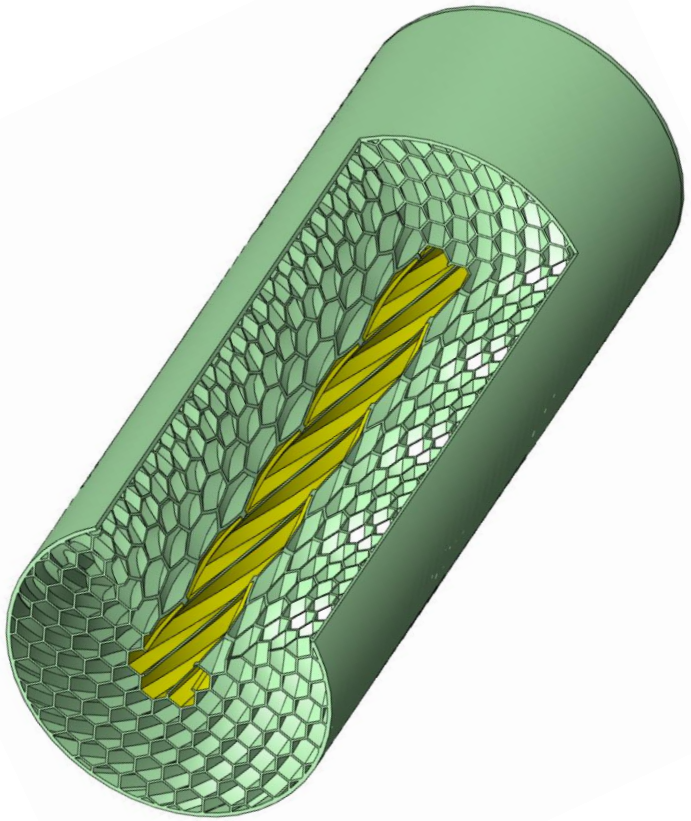
Printed fuel grain with Helical Ports

Conductive heating fixes diffusion-limited burning problem

Additive Manufacturing Allows New Capabilities

Multi-Jet Modelling Hybrid Motor Grains

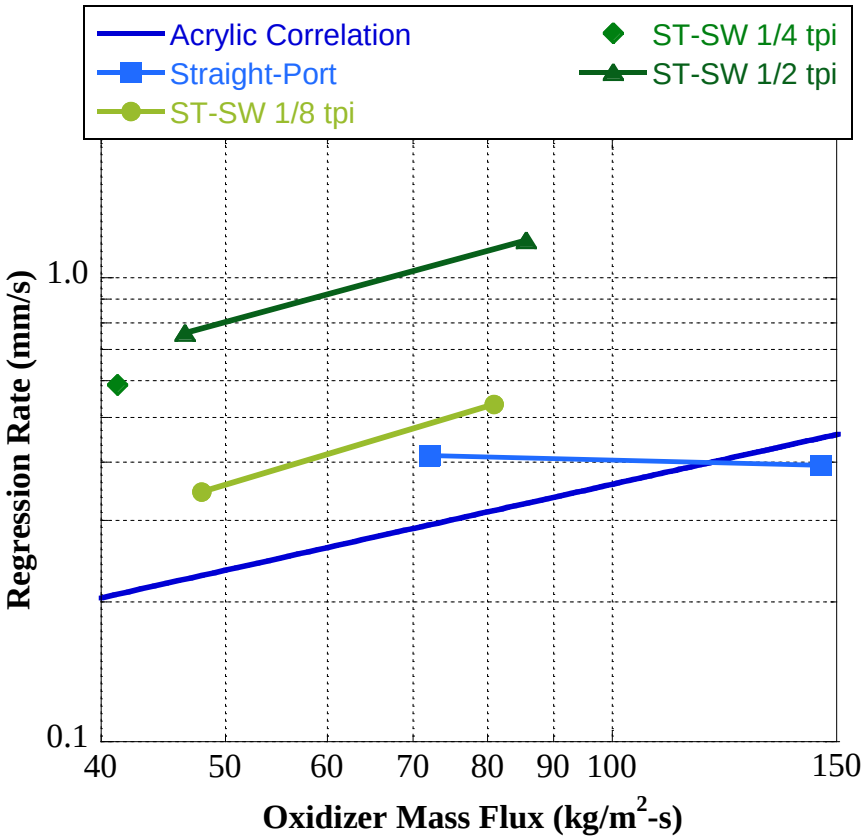
- Seamless production of multi-rate fuels
- Slow fuel manipulates Ox flow in fast fuel
  - *Increased thrust, Isp*
- High rate fuel contained in cells
- Integrated grain heater
  - *Energy required for heating is imparted on the ground (where it's cheap)*
  - *Fuels stored near their melting point burn faster*

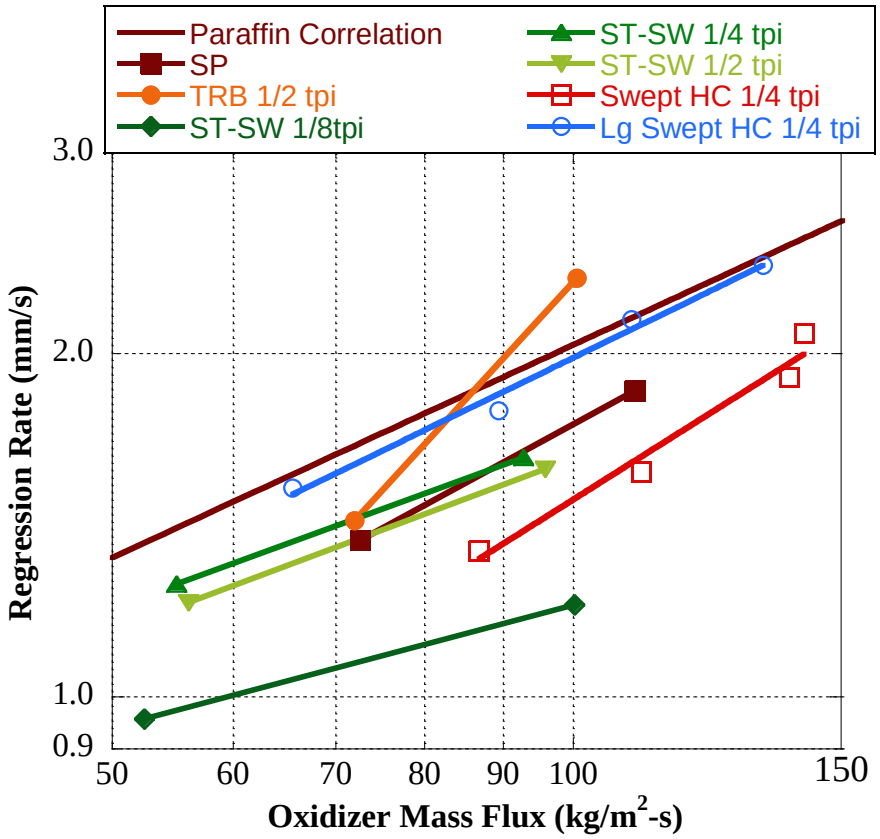


Additive Manufacturing Enables Multi-Fuel Grains

Multi-fuel increases efficiency

Test Results for Printed Motors





Performance Characterization of Hybrid Rocket Fuel Grains with Complex Port Geometries Fabricated Using Rapid Prototyping Technology

D. Armold, E. Boyer, B. McKnight, J. D. DeSain, J. K. Fuller, K. K. Kuo, and T. Curtiss

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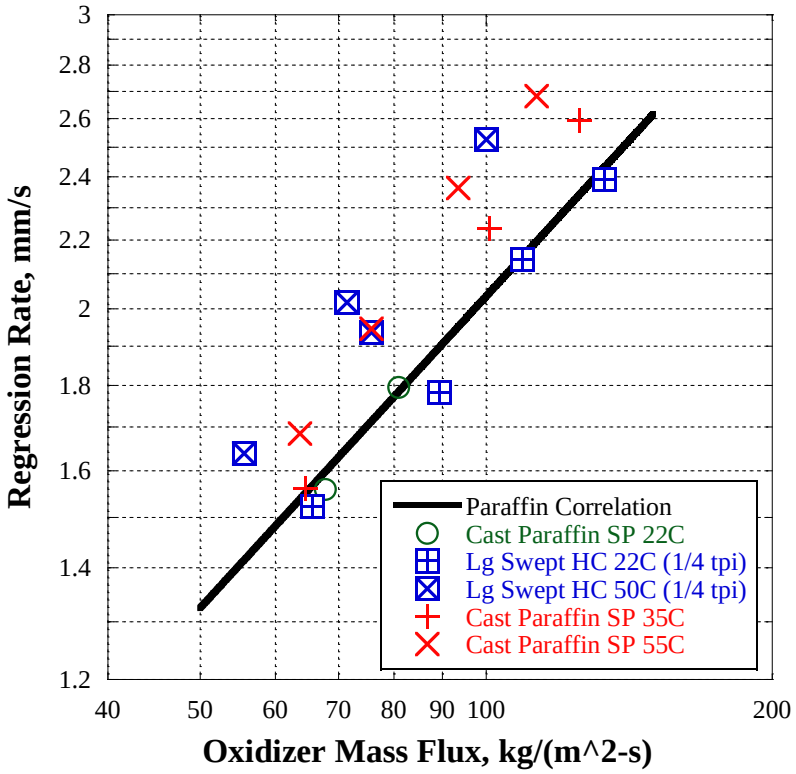
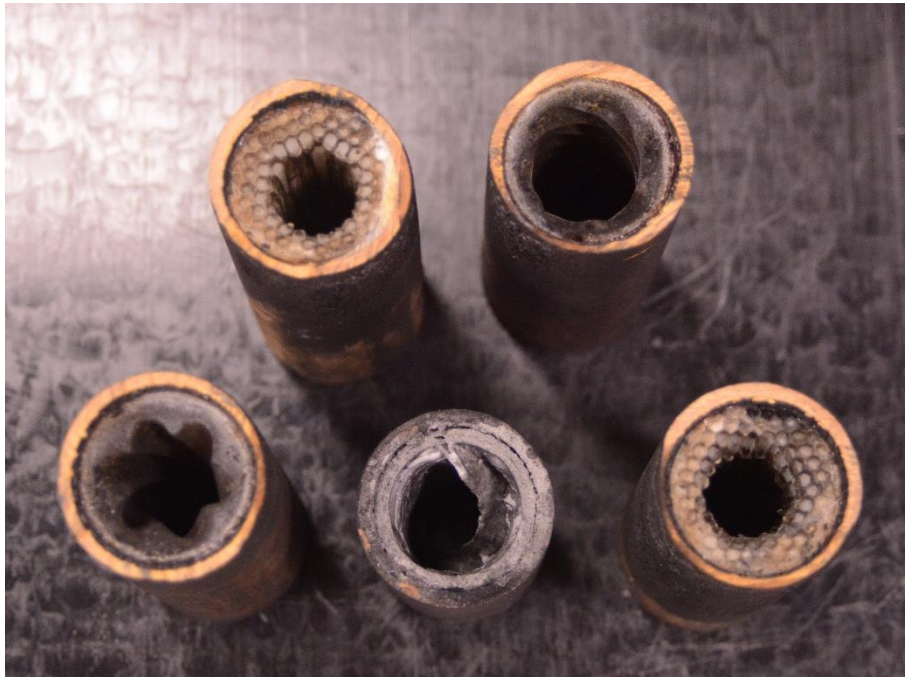
Test Results- Effects of Pre-Heating





Testing of Hybird Rocket Fuel Grains at Elevated Temperatures with Swirl Patterns Fabricated Using Rapid Prototyping Technology
Brendan R. McKnight, Derrick Armold[2], J. Eric Boyer[3], and Kenneth K. Kuo[4]
John D. DeSain[5], Jerome K. Fuller[6], Brian B. Brady[7], and Thomas J. Curtiss[8]
50th AIAA Joint Propulsion Conference

Significant Increase in Regression Rate without Drop in I_{sp}

Conclusions

- New possibilities offered by printed grain designs will facilitate design of rocket motors for exotic missions
- Increased performance makes printed hybrid rockets a more desirable alternative than cast hybrids
- Pre-heating grains increases performance

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